International Journal of EXERCISE SCIENCE

Original Research

Fluid Restriction Dehydration Increase Core Temperature During Endurance Exercise Compared to Exercise Induced Dehydration

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ABSTRACT

International Journal of Exercise Science 15(2): 166-176, 2022. This study aimed to evaluate the difference in heart rate and core temperature during aerobic exercise between two forms of dehydration: exercise-induced (EI) and fluid restricted (FR). Twenty-two subjects (N = 22; 83.35 ± 13.92 kg) completed the current study, performing a familiarization session, a pre-experimental exercise session, and two exercise testing sessions. The EI exercise trial (81.52 ± 13.72 kg) was conducted after performing exercise in a hot environment to lose three to four percent of body weight and partial rehydration. The FR exercise trial (81.53 ± 14.14 kg) was completed after 12 hours of fluid restriction. During both exercise sessions, subjects pedaled against a set resistance of 130 watts for 30 minutes. The main effect of hydration on Tc was significant, $F(1, 18) = 4.474$, $p = .049$, $\eta_p^2 = .199$ (Figure 2) with core temperature being greater during the FR trial compared to the EI trial (FR = 37.58 ± .06°C vs. EI = 37.31 ± .11°C). No significant interaction was found between hydration and time for HR, $F(2, 42) = 0.120$, $p = .887$, $\eta_p^2 = .006$. The main effect of time on HR was significant, $F(2, 42) = 119.664$, $p < .001$, $\eta_p^2 = .851$. Fluid restriction was associated with an increase in core temperature. An increased core temperature may negatively influence performance, and care should be taken to ensure proper hydration.

KEY WORDS: Hypohydration, aerobic performance, heart rate

INTRODUCTION

Fifty to 60% of total body mass in athletic populations is comprised of water, making water an essential nutrient for humans (1). The rate at which body water is lost exceeds any other nutrient within the body, making appropriate water intake highly important (1). Hypohydration is defined as a decrease in total body water. Simultaneously, dehydration has been described as the act of losing body water and is associated with a reduction in athletic performance (2).

As body-water is lost through dehydration, the resulting hypohydrated state can limit aerobic performance, leading to decreased peak power output and oxygen consumption (3). Hypohydration often increases body temperature and heart rate (HR), which negatively impacts aerobic performance and leads to a marked decrease in maximal work capacity (4). Reducing total body water by as little as two percent influences the central control mechanism that responds to thermoregulation and metabolic demand changes. Therefore, a decrease in total body water is associated with a decreased ability to dissipate heat, maintain core temperature (Tc), and maintain exercise intensity (1).

The process of dehydration can vary, leading to differing physiological manifestations and alterations in performance (4). Exercise-induced dehydration occurs when not properly replenishing water lost during an exercise session, resulting in an imbalance between water intake and water loss (5). Dehydration may also result from fluid restriction or voluntary dehydration (7). Fluid restriction and voluntary dehydration involve the prolonged inadequate intake of fluid (7). Research performed to evaluate hypohydration, and the negative impact on aerobic performance is bountiful, while very little research has been conducted to examine the comparison between these dehydration methods (8, 9, 10, 11, 12). Differences in the process of dehydration may impact physiological performance in unique ways. An optimal experimental design for hydration research has yet to be establish (31). Some research has found that dehydration does not negatively impact performance, especially with less than two percent loss in body weight (31) Other research has found that dehydration has negatively impacted endurance performance, especially when hydration levels were greater than two and a half percent of body weight loss (31). All of these studies utilize different methods of dehydration; fluid restriction, exercise induced, diuretics, heat exposure or a combination thereof. The differing methods of dehydration utilized in these studies muddy the water for setting guidelines for hydration practices and for the establishment of a research protocol when assessing dehydration.

Fluid restriction dehydration and exercise-induced dehydration are both associated with a decrement in performance due to the associated physiological changes (9, 11, 12). The physiological difference between fluid-restricted dehydration and exercise-induced dehydration during an aerobic exercise session has not been adequately evaluated. The purpose of this research study was to determine if a difference exists between fluid restriction and exercise-induced dehydration on Tc and HR during aerobic activities. The researchers hypothesized that heart rate and core temperature would be higher in the exercise induced session compared to the fluid restriction session.

METHODS

Participants

A large effect (f = .3), reported for Tc across varying hydration levels, was entered into an *a priori* power analysis (13, 14). To achieve 80% power, a sample size of 22 was deemed necessary. All subjects participated in at least 150 mins of exercise per week (12). All subjects had no known or diagnosed cardiac, metabolic, or renal disease. Any subject that answers 'yes' on the medical history questionnaire disqualified the subjects from participation in this study. A total of 30 male subjects volunteered to participate; one subject did not qualify for the study (history of rhabdomyolysis), and five subjects did not wish to participate in the study further. During testing, two subjects withdrew from the study. Twenty-two subjects completed the study.

Demographic information of the subjects is reported in Table 1. The Institutional Review Board read and approved all methods and procedures before any data collection. This research study was carried out in accordance to the International Journal of Exercise Science ethical standards (28).

Table 1. Demographic information.

Variable	*Mean*	*SD*
Time Spent Training (minutes/week)	502.27	211.52
Age (years)	20.91	1.97
Height (cm)	177.21	8.68
Weight (kg)	83.35	13.92
Body Fat (%)	12.77	5.97

Protocol

The Institutional Review Board read and approved all methods and procedures before any data collection. Subjects were recruited via email. Subjects who volunteered and met the inclusion criteria reported to the Human Performance Laboratory on four separate occasions. The four separate occasions included: (a) baseline testing/familiarization session, (b) a pre-experimental exercise session, and (c/d) two experimental sessions. The experimental sessions included 30 minutes of cycling. The subjects were randomized and counterbalanced for the order in which they complete the experimental protocol.

Familiarization session: Upon arrival to the Human Performance Laboratory, all subjects signed a written Informed Consent form, completed a medical history questionnaire, and demographics questionnaire. Nude body weight was recorded to be used as the baseline body weight (Detecto Scale Company, Webb City, MO). Body composition was estimated through the use of the Bodpod (Cosmed The Metabolic Company, Concord, CA). During the familiarization session, subjects completed an initial 30 minute cycling bout to become accustomed to the Velotron with resistance set at 130 W (Razor Mate, Seattle, WA; 15). Following the assessment of body composition, subjects ingested 250 mls of water in bolus to ensure a euhydrated state for the familiarization session.

Experimental sessions: Subjects completed an exercise-induced dehydration (EI) protocol and a fluid restricted dehydration (FR) protocol (Figure 1). For all experimental sessions, hypohydration was defined as a two to three percent decrease in body weight or a urine-specific gravity that is greater than 1.010. (6) The day prior to both experimental sessions, the researched met with the subjects in order to provide them with a hard copy of directions to follow for the time leading up to testing. All experimental sessions were completed at the same time of day.

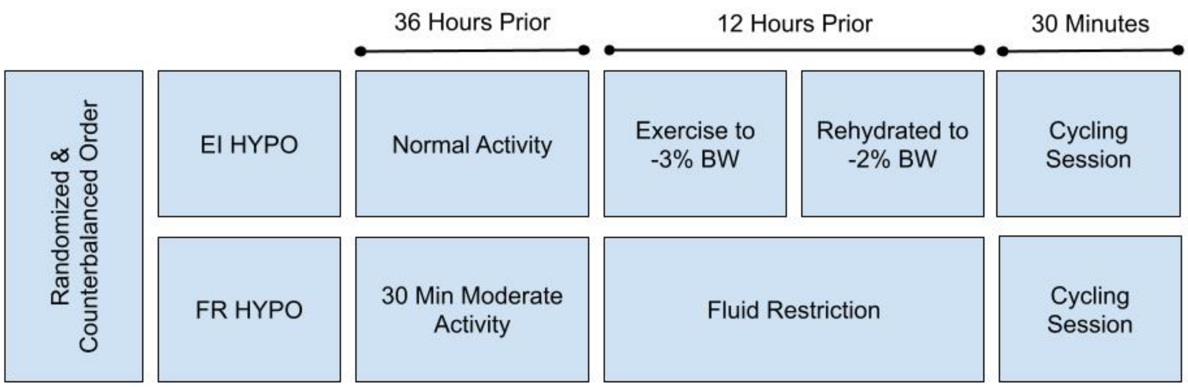

Figure 1. Schematic of experimental sessions.

In the 36 hours prior to the EI exercise session, all subjects were asked to maintain their normal daily activity and hydration practices. In the 12 hours prior to the EI exercise session, subjects completed a pre-experimental session in an environmental chamber. The average temperature of the environmental chamber was 34.15 ± 1.9° Celsius. The subjects cycled on a Monarch cycle ergometer with a resistance of 3 kg until reaching a three to four percent of body weight deficit. Every 15 minutes a weight measurement occurred after the individual is wiped down of sweat and removed shirt, sneakers, and socks. During the pre-experimental exercise session, the subject did not intake any fluid and exercised until reaching a minimum of three percent decrease in body weight. If the subject felt any adverse side effects (nausea, dizziness, shortness of breath, etc.), the session was terminated. One subject stopped the pre-experimental session due to adverse side effects and subsequently withdrew from the study. In order to partially rehydrate, subjects received 473 ml of water for every pound lost to represent 1.5% of body weight. Room temperature water was provided to subjects to drink in the 12 hours after completing the pre-experimental trial and before the EI exercise session, in order to partially rehydrate to two to three percent decrease in body weight. Subjects were asked to return the empty water bottles that were provided when they returned to the Human Performance Laboratory. Subjects were also asked to avoid foods with high water content in the 12 hrs before exercise testing, such as fruits or soups. If the subject had not met the necessary weight, urine-specific gravity was utilized to confirm hypohydration. A urine-specific gravity that is greater than 1.010 was accepted as a hypohydrated individual.

Prior to the FR exercise session, all subjects were asked not to consume any fluid in the 12 hrs before exercise testing. Subjects were asked to complete a 30 min exercise session in the 24 hours before the start of the FR period and consume 473 ml of water for every pound that represented two percent of body water after completing the exercise. The exact water amount to intake was provided to the subject as calculated by the researchers. Subjects were also asked to avoid foods with high water content in the 12 hrs before exercise testing, such as fruits or soups. If the subject had not met the necessary weight, urine-specific gravity was utilized to confirm hypohydration. A urine-specific gravity that is greater than 1.010 was accepted as a hypohydrated individual.

Subjects were provided with the core temperature pill the evening prior to the experimental session and were given written instructions to take the ingestible core temperature pills one hour prior to their session (HQInc., Wireless Sensing Systems & Design, CorTemp Sensor, Palmetto, FL). Experimental sessions (familiarization, EI and FR) occurred between 5:00 am and 12:00 pm to allow USG to be measured using the first-morning void (6, 18, 19). Upon arrival, subjects were asked to void their bladder to collect urine and measure urine-specific gravity. Subjects had nude body weight measured and compared to familiarization baseline weight measurement. All experimental sessions (familiarization, EI, and FR) were completed in a thermoneutral environment. All subjects wore a heart rate monitor throughout the experimental sessions (Polar Electro, Kempeple, Finland). HR and Tc were recorded at baseline. Subjects pedaled against the set resistance of 130 watts for 30 minutes and instructed to cover as much distance as possible; total distance covered was recorded. Measurements of HR and Tc occurred at 15 minutes and 30 minutes.

Statistical Analysis

All statistical analyses were performed using IBM SPSS version 21.0 (Armonk, NY) with an alpha level set at .05. Prior to any statistical analysis, data screening occurred to check for missing data, outliers (≥ ± 3.3 SD), normality (≥ ± 3.3 SD), and basic assumptions. Three missing values were indicated for Tc during the FR trial, resulting in 13% missing cases. Descriptive statistics were calculated as mean ± standard deviation for height, weight, body fat percentage, distance covered, pre-experimental chamber temperature and subjects' age. Four paired samples *t*-tests were conducted to examine differences between the two experimental trials for weight loss, percent weight loss, USG, distance covered and environmental conditions. Two 2 x 3 Repeated Measures Factorial ANOVAs were conducted to examine HR and Tc's differences regarding different dehydration methods at three different time points (i.e. pre-exercise, 15 minutes, 30 minutes). The repeated measure two-level factor was dehydration (i.e. EI and FR).

RESULTS

Tc was measured in all subjects (N = 22), but in four cases, a failure of the Tc pill occurred. The missing data for Tc in the FR trial was handled through a pairwise deletion of the individual score from the variable. One missing value was indicated for Tc during the EI session; mean imputation was done to replace the missing value (n = 19). No outliers were present for HR or Tc and all dependent variables were normally distributed based on skewness and kurtosis statistics of (38). All basic assumptions for a repeated measures factorial ANOVA were met.

During the pre-experimental exercise session, the average temperature in the environmental chamber was 34.16 ± 1.98 °C with an average humidity of 17.34 ± .95 percent. The average percentage of weight lost experienced during the pre-experimental exercise session was 3.061 ± 0.717 percent. The average time spent within the environmental chamber was 51.818 ± 8.947 mins. Changes in weight, USG and distance during experimental sessions is shown in Table 2.

Table 2. Experimental Session Baseline Data and Distance Covered (Mean ± *SD)*

Variable	*FR*	*EI*	*p Value*
Weight at start of session (kg)	81.53 ± 14.14	81.52 ± 13.72	.922
Weight loss from baseline (%)	2.25 ± 0.44	2.21 ± 0.87	.922
USG	1.030 ± .005	1.024 ± .004	.066
Distance covered (miles)	5.29 ± 1.51	5.01 ± 1.40	.012
Ambient temperature °C	21.52 ± 0.36	21.47 ± 0.24	.648
Humidity (%)	22.18 ± 0.39	22.18 ± .39	1.00

No significant interaction was found between hydration and time in terms of Tc, $F(1, 24) = 0.062$, $p = .987$, $\eta_p^2 = .001$. Tc at 15 minutes (37.582 ± .049°C) was greater than baseline (36.93 ± .093°)and less than Tc at 30 minutes (37.85 ± .055°C). The main effect of hydration on Tc was significant, $F(1, 18) = 4.474$, $p = .049$, $\eta_p^2 = .199$ (Figure 2) with core temperature being greater during the FR trial compared to the EI trial (FR = 37.58 ± .06°C vs. EI = 37.31 ± .11°C).

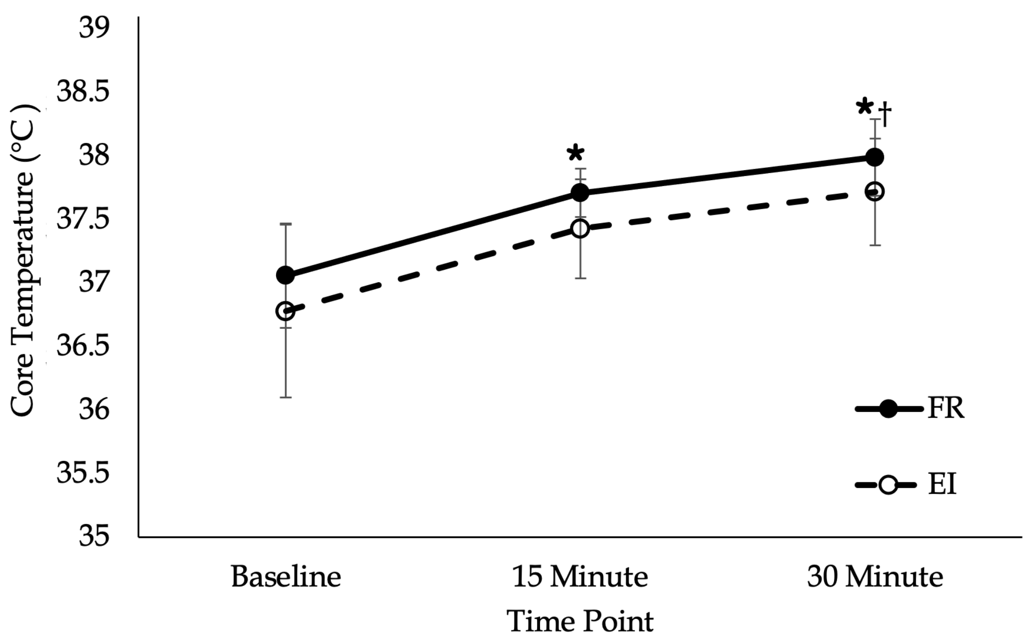

Figure 2. Change in core temperature from pre-exercise, 15 minutes, and 30 minutes of exercise in both hydration conditions. * Indicates a statistically significant difference from baseline ($p < .05$). † Indicates a statistically significant difference from midway to post-exercise ($p < .05$). Error bars represent mean ± standard deviation.

No significant interaction was found between hydration and time for HR, $F(2, 42) = 0.120$, $p = .887$, $\eta_p^2 = .006$. The main effect of time on HR was significant, $F(2, 42) = 119.664$, $p < .001$, $\eta_p^2 = .851$. Heart rate was significantly different from baseline (80 ± 2 bpm) to 15 minutes (136 ± 4 bpm) and from baseline to 30 minutes (148 ± 2 bpm) but not significantly different from 15 minutes to 30 minutes (Figure 3).

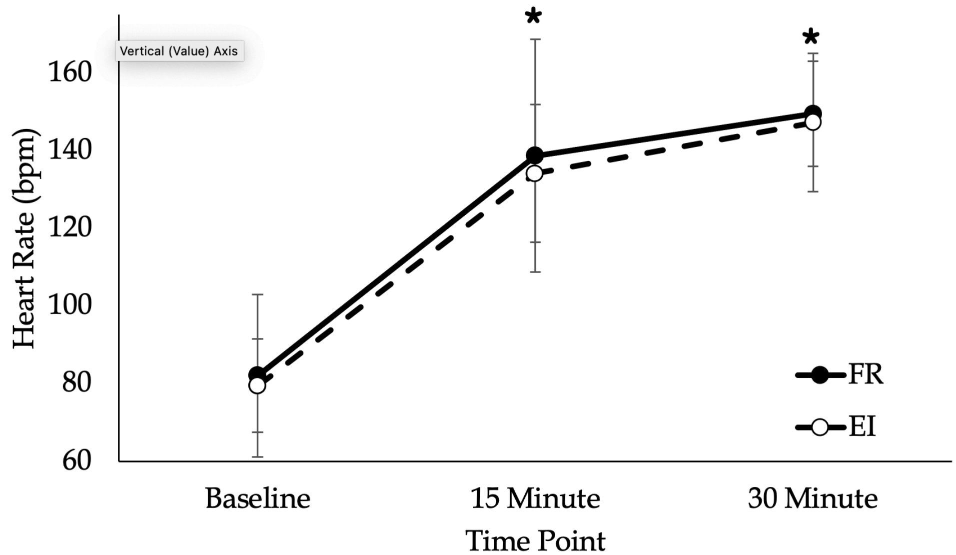

Figure 3. Shows the change in heart rate (bpm) from baseline to the 15 minutes and to 30 minutes in both the fluid restricted and exercise induced trial. * Indicates a statistically significant difference from baseline ($p < .05$). Error bars represent mean ± standard deviation.

DISCUSSION

The combination of multiple physiological impairments associated with the hypohydrated state has been proposed to impact aerobic endurance performance (23) negatively. Dehydration through fluid restriction or inadequate water replacement after exercise can lead to a hypohydrated state; how these two dehydration methods impact physiological function can vary (4). The current study aimed to examine if a difference exists between EI and FR dehydration in terms of HR and Tc. The researchers' initial hypotheses were incorrect; the dehydration method did not impact HR, while Tc was higher in the FR session than the EI session. Both HR and Tc followed the expected response to exercise, increasing as exercise time increased.

HR typically rises in proportion to exercise intensity, allowing the cardiovascular system to meet the demand for oxygen at the working tissue (26). HR will continue to rise from resting levels until reaching a steady-state condition (26). In previous research, dehydration has influenced HR during an exercise session, causing an increase in HR throughout an exercise session despite reaching steady-state (21). Although not statistically significant, an increase in HR was observed from 15 mins to 30 mins in both the EI and FR session.

Caldwell and colleagues aimed to evaluate how sauna, diuretic and exercise induced hypohydration impacted physiological performance during maximal exercise and at anaerobic threshold (4). The researchers did not find differences in the physiological manifestations, except for Tc, between exercise-induced hypohydration and fluid restricted hypohydration (4). Heart rate was not significantly different between the different dehydration methods at anaerobic threshold and maximal exercise (4). Within this current study, Tc and HR followed similar patterns between the two dehydration methods. No difference was found between EI and FR in HR, indicating a similar HR response to meet demand at the tissues between the two sessions. Tc rose from baseline to 15 mins to 30 mins, as expected. Tc was statistically different between the FR and EI sessions. Tc rises in response to an increased metabolic rate when heat loss mechanisms cannot sufficiently dissipate heat (25). As an individual participates in exercise, adenosine triphosphate (ATP) is broken down to perform muscular work, resulting in heat production (24). A minimal difference in Tc was seen with a mean difference of 0.27°C and the small effect size (η_p^2 = .199), with Tc being higher in the FR session compared to the EI session.

A previous study examined the impacts of hypohydration on Tc during endurance exercise in hot and temperate environments, finding that 5% hypohydration in a hot environment is associated with a 0.16° C increase in core temperature (32). Sawka and colleagues examined graded dehydration on thermoregulatory response to exercise (32). The dehydration method combined fluid restriction and exercise within the study, making the analysis of both dehydration methods impossible (30). This study utilized exercise in a hot environment which can further exacerbate the thermoregulatory stress experienced by the subjects. In a temperate environment within the current study, core temperature was statistically different in the fluid restriction protocol. Previous research has demonstrated that hypohydration and the associated hypovolemia decreases sweat rate during exercise (32). By diminishing the sweat rate, heat loss mechanisms are reduced, and Tc rises. Future research should aim to look at the alteration in sweat rate between FR and EI dehydration situations.

Increased core temperature has been proposed as a critical limit to exercise, especially when exercise occurs in a hot environment (36). When reaching critical core temperature, there is a reduced CNS activation of skeletal muscle. Reduction in activation in skeletal muscles can reduce overall physical performance (36). It has been reported that reduced CNS activation occurs when Tc reaches 38 ° C (37). If FR dehydration results in higher Tc during exercise, it is possible that exercise performance would be limited to a greater extent compared to EI dehydration. Within the FR session, 11 subjects had a Tc greater than 38 °C, while in the FR session only 1 subject had a Tc greater than 38 °C. The greater number of subjects that reached 38 °C within the FR session, may impact performance as a result of the reduction in CNS activation. Performance may be further impacted based on the environment that the exercise is occurring within. The exercise duration during this study was 30 minutes, many endurance activities are longer in duration and may be further negatively impacted by dehydration. A hot environment combined with FR dehydration may significantly decrease performance but further research is needed to evaluate this.

One of the limitations of the current study is the use of only trained males. Hypohydration may impact females and untrained individuals differently. Females have a different sweat response compared to males (29). Due to the differences in sweat response female may not experience EI hypohydration to the same degrees as males as they potentially lose less water during the endurance exercise activity (29). Untrained individuals may experience a greater performance decrement due to the unfamiliarity of performing in a hypohydrated state (34). Future research should explore the impact of both EI and FR on endurance performance within these populations. A limitation associated with this study is the combination of heat stress in exercise-induced hypohydration. The combination of heat stress may have impacted performance negatively. Implementing a twelve-hour recovery aimed to help combat the consequence of the heat stress, but in combination with inadequate fluid, replacement may not have been enough in this situation. Evaluating EI dehydration with and without exposure to heat stress compared to euhydration and FR dehydration to see if a performance difference still exists could be explored in future research.

This study demonstrated that FR will cause a higher increase in Tc during exercise in a thermoneutral environment compared to EI. The increase in Tc may negatively impact endurance performance and, possibly, to a greater extent when exercise is longer than 30 minutes in duration. When evaluating hydration on performance, it is important to note that FR was associated with a higher Tc which may influence the physiological results being collected. Researchers should take into consideration this elevated temperature when establishing experimental design for hydration studies. Practitioners (coaches, athletes, medical staff) should educate exercising individuals on the importance of proper hydration and not relying on thirst as an indicator to drink water. Care should be taken to avoid training and competing when an exercising individual is dehydrated, especially due to lack of fluid intake.

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